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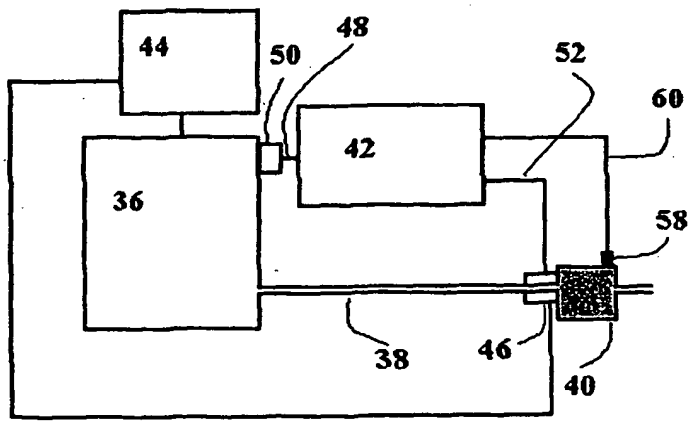
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: IMPROVEMENTS IN PARTICULATE FILTERS



(57) Abstract: A vehicle engine exhaust includes a particular filter regeneration control system including a controller (42) and first and second regeneration activators including an air intake throttle (50) and an electrical heater (46). As a result engine efficiency losses with higher back pressure levels can be traded off against improved self propagation of incineration at higher particulate loadings.

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IMPROVEMENTS IN PARTICULATE FILTERS

The invention relates to particulate filters, in particular diesel particulate filters (DPF's).

The use of DPF's, also known as diesel particulate traps, to collect particulate emissions in the exhaust systems of diesel vehicles is well known and a simplified schematic diagram is shown in Fig. 1. A vehicle 10 includes a diesel engine 12 having air intake and fuel intakes 14 and 16 respectively, an exhaust 18 and a DPF 20 in the exhaust line.

In essence the DPF comprises a porous media through which the exhaust gases pass and which filters out particulates. Various filter materials are known including ceramic monoliths, wire mesh and so forth. Fig. 2 shows a simplified diagram of a known DPF arrangement in which particulate laden exhaust gas 24 is forced through a filter material 22 which provides the only route between closed passages 30,32. The cleaned exhaust emission 26 exits the outlet passage 32 leaving behind particulate 28 on or in the filter 22. Multiple passage arrangements are known and arrangements such as these have been found to reduce emissions of particulate by 90% or more.

A known problem with DPF systems is that as particulate matter builds up and the filter effectively becomes clogged, the back pressure on exhaust gases will also increase. The preferred scheme currently used for overcoming this problem is termed "regeneration" by which the particulates are effectively incinerated in the filter, regeneration takes place before a large amount of particulate builds up, by triggering regeneration at short time intervals. However diesel engine exhausts are relatively cool and as the thermal efficiency of engines improves the exhaust temperatures are decreasing further. Accordingly the diesel exhaust temperature alone may not be sufficient to raise

the filter temperature to the self-oxidation temperature of the particulate at which a self-sustaining action can take place under the correct conditions of temperature, oxygen concentration and mass air flow.

Various schemes have been proposed in the art to initiate regeneration including using catalysts either coated on the DPF itself or carried in the fuel. International Patent Application No. WO 00/60228 proposes an alternative system of increasing the exhaust gas temperature by injecting fuel into cylinders of the engine during the expansion stage. US Patent No. 5,171,337 to Pollock relates to a filter unit further comprising an electrical heating element to raise the temperature of the filter sufficiently to initiate regeneration. In addition known proposals include throttling the air intake to the engine hence increasing exhaust gas temperature.

Various problems arise with the known arrangements including increased fuel/electricity consumption and reduced engine efficiency.

A further problem with existing regeneration schemes is that the exhaust temperature is dependent upon driving conditions. In typical urban conditions where an engine runs on a low load for a short period and is switched off frequently, exhaust temperatures can be too low to induce particulate burning without excessive additional heater work whereas long driving periods at high loads will create exhaust temperatures more conducive to regeneration without additional heating. As a result existing schemes may face particular problems during low load conditions of this kind.

According to the invention there is provided a particulate filter regeneration control system for an engine having an exhaust comprising a particulate filter for filtering an exhaust, and first and second regeneration activators in which the regeneration activators comprise a filter heater and an air inlet throttle to the engine. As a result regeneration can be achieved at optimum

engine efficiency even in urban or other low exhaust temperature driving conditions.

According to the invention there is further provided a particulate filter regeneration control system comprising a particulate filter, at least one regeneration activator, a particulate load sensor and a controller arranged to trigger the regeneration activator when the particulate load in the filter falls in the upper part of the range 8-10g/l, more preferably approximately 10g/l. The invention hence identifies an optimum load value for trading off increased back pressure against improved regeneration conditions.

According to the invention there is yet further provided a particulate filter regeneration control system comprising a particulate filter, first and second regeneration activators, a regeneration condition sensor and a controller in which the controller selectively triggers one or both of the activators dependent on the sensed regeneration condition. As a result an efficient regeneration program can be tailored to current load conditions.

Further preferred features and methods according to the invention are set out in the appended claims.

Embodiments of the invention will now be described by way of example with reference to the drawings of which:

Fig. 1 shows a schematic view of a known DPF scheme;

Fig. 2 shows a detail of a typical DPF;

Fig. 3 shows a DPF control scheme according to the present invention; and

Fig. 4 shows a plot of fuel consumption against DPF loading.

Referring to Fig. 3 an improved DPF scheme according to the present invention includes a diesel engine 36 having an exhaust 38 and a DPF 40

mounted thereon, a controller 42 and a flywheel mounted electrical device (FMED) 44. The DPF includes an electrical heater 46 and the engine includes an air inlet throttle 50.

The various components individually will be well known to the skilled person. In the preferred embodiment the diesel engine is a 1.2 litre engine and forms part of a mild hybrid arrangement in which the FMED 44 operates at 42 volts and the maximum power of 6 kilowatts. The FMED 44 is used to power the heater 46 and in a typical mild hybrid implementation can also provide torque boast at low engine speeds, regenerative braking and powering of additional electrical ancillary devices and can be for example of the type known as a Continental ISAD – Integrated Starter, Alternator and Damper.

The DPF may be of any appropriate type for example a round geometry SiC monolith of dimensions length 6 inches (15.24cm) and diameter 5.66 inch (14.38cm) of the type sold by Corning and Ibiden. The electrical heater is a 42 volt metal foil element heater of the type provided by Emitec GmbH of Germany primarily providing heating of the monolith by convection. In the embodiment shown it is mounted very closely upstream to the DPF and hence provides additional direct heating of the front face of the DFP monolith by radiation as the element approaches its upper temperature range. The heater is dimensioned to produce about 5.9kW of total heat at 42 volts.

The controller 42 can be an appropriately programmed micro processor which can be stand-alone or integrated with an engine management system. It includes control lines 48 and 52 to the air inlet throttle 50 and heater 46

The regenerative control scheme implemented by the controller 42 addresses low load conditions such as in during urban driving, in which exhaust temperatures may not rise high enough to initiate regeneration without significant additional electrical heating which in turn increases fuel

consumption and potentially exceeds the power available from the FMED 44. In particular the complementary exhaust temperature raising mechanism of adjusting the air intake via throttle 50 is also implemented. The air throttle 50 may be of any appropriate type. In a preferred embodiment the throttle control comprises a combination of inlet throttling and variable nozzle turbocharger (VNT) control.

Yet further in conventional systems DPF is triggered sufficiently frequently that particulate loading remains at a low level, determined so as to avoid high levels of back pressure being fed back to the engine from a partial blockage of particulate. The present invention recognises, however, that the engine efficiency losses with higher back pressure levels can be traded off against improved self-propagation of incineration at higher particulate loadings. Accordingly the controller 42 further includes a particulate loading sensor 58 and sensor line 60 to determine when the particulate loading of DPF 40 reaches a predetermined, relatively high level – at that stage regeneration is triggered by activation of the air intake throttle 50 and electrical heater 46.

The loading sensor can be of any appropriate type as will be well known to the skilled person but in the preferred embodiment comprises a ΔP sensor coupled with a exhaust volumetric flow sensor. The ΔP sensor measures the pressure drop across the filter and this value allows the loading to be determined as will be well known to the skilled person.

According to this scheme oxygen based DPF regeneration occurs, without the need for fuel borne catalyst or active wash coat as the required temperature of around 550°C required to initiate the particulate burning reaction in a non-catalysed filter is attained. Furthermore the DPF is regenerated using the minimum amount of energy possible as the particulate burning reaction according the scheme becomes self-sustaining as the correct conditions of

temperature, oxygen concentration and mass air flow are met.

In particular it is found that regeneration according to the scheme occurs effectively even during low load conditions such as experienced during urban driving. In the particular embodiment discussed herein it is found that at DPF particulate loadings of 25g (10g/l), the temperature rise in the exhaust gas induced by inlet throttling allows an electrically heated regeneration powered by the FMED to take place even under low load conditions with 85% of the particulate burnt off within 300 seconds. Furthermore it is found that, over a typical drive cycle such as the new European drive cycle (NEDC) a fuel consumption penalty of only 0.91*l*/100km is incurred when regeneration takes place during the cycle. More generally it is found that particulate loadings in the upper part of the range 8-10g/1 provide the desired conditions for the invention to operate. As a result the invention identifies an optimum point in the fuel consumption against loading curve shown very roughly in Fig. 4, which is substantially flat in this region, such that the improved regeneration conditions at the upper end of the range combine with the minimal compromise on back pressure to provide optimum operation.

It will further be appreciated that enhanced control schemes can be implemented in which the air intake throttle 50 is activated selectively dependent upon engine load such that it only supports the electrical heater when the regeneration temperature would otherwise not be attained. To implement this the controller can, for example, have a simple exhaust temperature sensor and an engine mass flow rate sensor. From the readings taken from these the controller can determine whether the electrical heater alone can provide the required ΔT to initiate regeneration and if not can institute inlet throttling as well. It will be appreciated that the controller can take measurements directly or can access appropriate data from an engine management system dependent

on the type of load sensor employed. Yet further the system can provide model-based predictive regeneration. Where a model of loading level is constructed against engine conditions and/or time then the regeneration point can be derived in advance in real time based on engine mapping. This can embrace more complex schemes which determine whether throttling will be required and can be integrated into a general hybrid predictive control scheme whereby optimum load sharing between power sources is derived based on predicted loads.

It will also be appreciated that appropriate particulate loading values triggering regeneration can be determined for other systems empirically by monitoring fuel consumption/exhaust back pressure and filter/heater temperature (to avoid exceeding safe temperature limits in the filter when the particulates are burnt at very high loadings) against FMED drain. Alternatively the system can be calibrated using appropriate modelling techniques, for example modelling the filter temperature, and the exhaust pressure drop against particulate loading and exhaust volume flow rate providing a measure of increased fuel consumption to define the optimum DPF particulate loading at which to trigger regeneration. An appropriate pressure drop sub-model is characterised by the following equation:

$$\Delta P = \frac{\mu Q}{2V_{trap}}(\alpha + w_s)^2\left[\frac{w_s}{k_0\alpha} + \frac{1}{2k_{part}}\ln\left(\frac{\alpha}{\alpha - 2w}\right) + \frac{4FL^2}{3}\left(\frac{1}{(\alpha - 2w)^4} + \frac{1}{\alpha^4}\right)\right]$$

where μ: exhaust dynamic viscosity

Q: exhaust volumetric flow

V_{trap}: DPF volume

α: DPF honeycomb filter cell size

w_s: filter wall thickness

k_0: clean wall permeability

k_{part}: particulate permeability

F: constant

L: effective channel length.

It will be appreciated that the invention can be applied to other particulate filters where the particulate bearing gas temperatures are insufficiently high to trigger self-sustaining regeneration or vary dependent upon system loadings. It will further be appreciated that any type of DPF and specific regeneration triggering loading value within the ranges discussed above can be adopted as desired.

CLAIMS

1. A particulate filter regeneration control system for an engine having an exhaust comprising a particulate filter for filtering an exhaust, and first and second regeneration activators in which the regeneration activators comprise a filter heater and an air inlet throttle to the engine.

2. A system as claimed in claim 1 further comprising a controller to trigger the regeneration activator when the particulate load in the filter falls in the range 4-20g/l.

3. A system as claimed in claim 2 in which the controller is arranged to trigger the regeneration activator when the particulate load in the filter falls in the range 4-10g/l, more preferably 8-10g/l, most preferably approximately 10g/l.

4. A system as claimed in any preceding claim further including a regeneration condition sensor in which the controller selectively triggers one or both of the activators dependent on the sensed regeneration condition.

5. A system as claimed in any of claims 2 to 4 further including a sensor for sensing engine load directly or indirectly in which the controller selectively

triggers one or both of the regeneration activators dependent upon sensed engine load.

6. An engine having an exhaust and a system as claimed in any preceding claim in which the exhaust is filtered by the particulate filter.

7. An engine as claimed in claim 6 comprising a diesel engine and in which the particulate filter is a diesel particulate filter.

8. An engine as claimed in claim 7 further comprising an electrical machine in hybrid or mild-hybrid configuration arranged to power a regeneration activator.

9. An engine as claimed in any of claims 5 to 8 when dependent on claim 4 in which the regeneration condition sensor comprises at least one of an exhaust temperature sensor and an engine mass flow rate sensor.

10. An engine as claimed in any of claims 5 to 9 when dependent on any of claims 2 to 4 in which the controller triggers regeneration based on a predicted particulate load derived from sensed engine conditions.

11. A vehicle including a system or engine as claimed in any preceding claim.

12. A particulate filter regeneration control system comprising a particulate filter, at least one regeneration activator, a particulate load sensor and a controller arranged to trigger the regeneration activator when the particulate load in the filter falls in the upper part of the range 8-10g/l, more preferably approximately 10g/l.

13. A particulate filter regeneration control system comprising a particulate filter, first and second regeneration activators, a regeneration condition sensor and a controller in which the controller selectively triggers one or both of the activators dependent on the sensed regeneration condition.

14. A method of regenerating a particulate filter comprising the steps of sensing a particulate load and triggering at least one regeneration activator when the sensed load exceeds a threshold in the upper part of the range 8-10g/l.

15. A method of regenerating a particulate filter have first and second regeneration activators in which one or both activators are selectively triggered dependent on a sensed regeneration condition.

16. A system, engine, vehicle and method substantially as herein described with reference to Fig. 3.

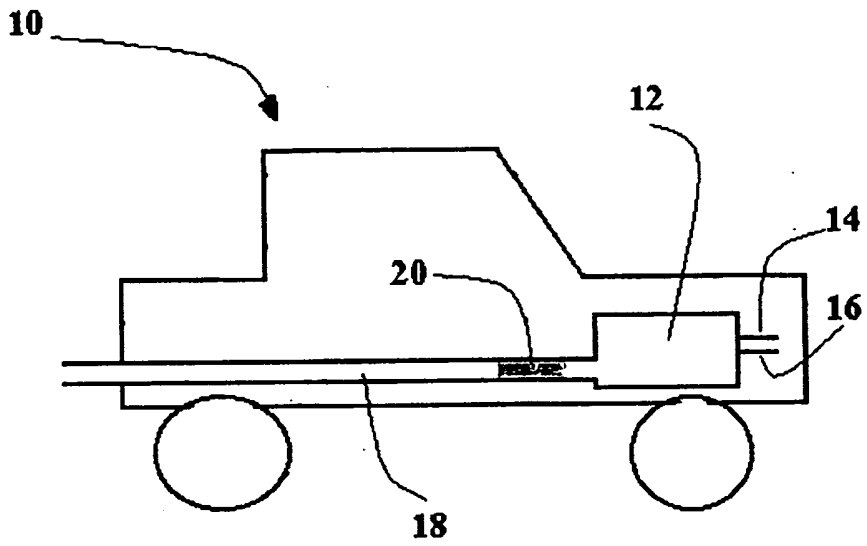

Fig. 1

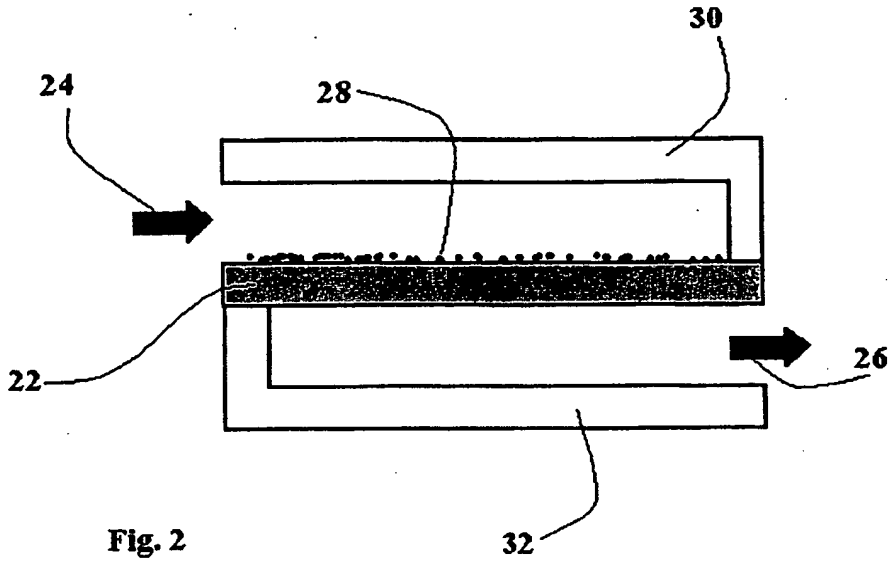

Fig. 2

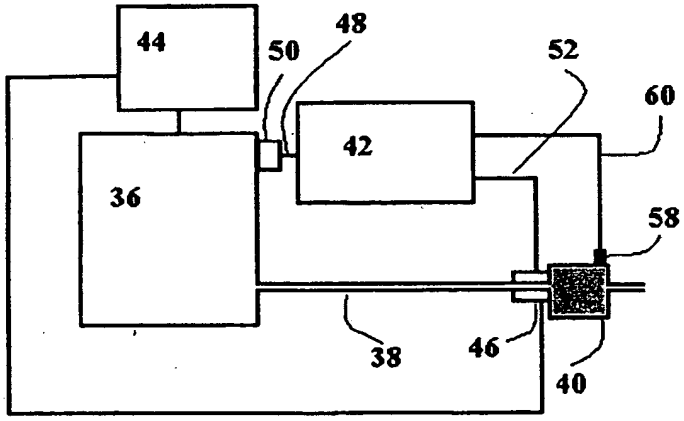

Fig. 3

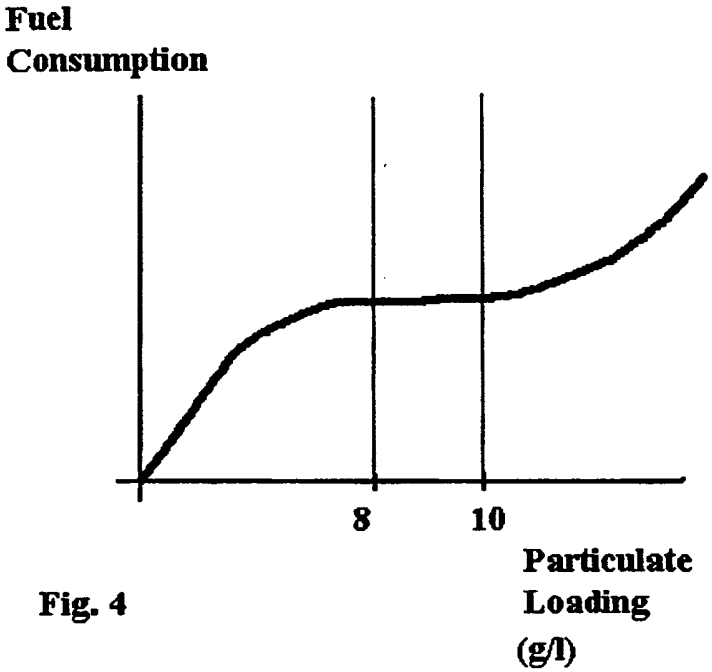

Fig. 4

INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/GB 02/02625

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F01N3/027 F01N9/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 195 318 A (KANESAKI NOBUKAZU ET AL) 23 March 1993 (1993-03-23) column 3, line 31 -column 4, line 27 table 1 claims 3,7,10,13 figure 7 ---	1,4-6,9, 13-15
X	US 4 685 290 A (SAKAKIBARA YASUYUKI ET AL) 11 August 1987 (1987-08-11) column 6, line 30 -column 6, line 39 claims 2,8 figure 2 ---	1,4-6,9, 13-15
X	US 4 549 398 A (TAKAMA KENICHIROU ET AL) 29 October 1985 (1985-10-29) abstract column 5, line 41 -column 6, line 52 figures 1,2 --- -/--	1,4-7, 13-15

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 August 2002	19/08/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ikas, G

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 603 907 A (MAGNET MOTOR GMBH) 29 June 1994 (1994-06-29) abstract claims 1,2,6,11,12,14-17 figure 1	6-8,11
A	US 5 458 673 A (TAKEUCHI TAKAYUKI ET AL) 17 October 1995 (1995-10-17) column 2, line 41 -column 3, line 42 column 4, line 67 -column 5, line 57 figures 1,5A,5B	2,3,9, 12,14
A	EP 0 411 445 A (CUMMINS ENGINE CO INC) 6 February 1991 (1991-02-06) abstract	10

INTERNATIONAL SEARCH REPORT

national application No.
PCT/GB 02/02625

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 16
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box I.2

Claims Nos.: 16

Independent claim 16 relates to a product and method defined by general references to the desciption and to the drawings without specifying desirable technical features or method steps.

According to Rule 6.2(a) PCT, claims should not contain such references exept where absolutely necessary, which is not the case here.

The present wording of claim 16 lacks clarity (Article 6 PCT) and consequently renders a meaningful search over the whole of the claimed scope impossible.

Thus, the search has been carried out for claims 1 to 15 only.

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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